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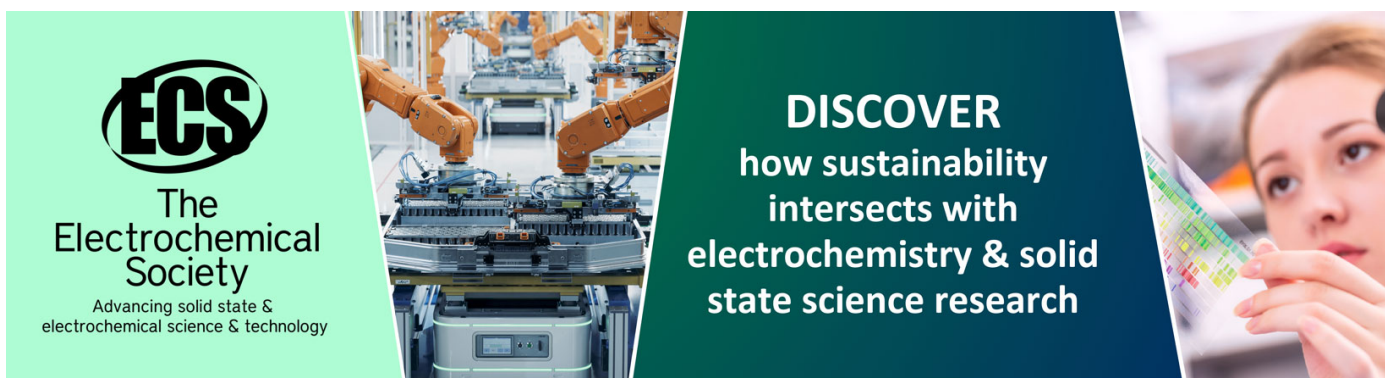
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To cite this article: Chunsheng Yang *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **727** 012014

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Design and Research of Convenient Cantilever-Unloading Bracket for Antenna

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Abstract. In spacecraft assembly integration and test, zero gravity unloading of antenna is necessary during antenna deployment/closure test. To meet the requirement of antenna unloading condition in EMC test stage, a convenient cantilever type universal antenna unloading bracket is designed. The system consists of the main body of the cantilever device, the first-stage arm, the second-stage arm and the pulley system. Through analysis and calculation, the system can meet the space requirement, friction resistance requirement, strength and deformation limitation in the unloading process. It can provide technical reference and basis for zero gravity deployment/closure test for various surface antennas of spacecraft in the assembly process.

1. Introduction

In the process of spacecraft assembly integration and test(AIT), the deployment and closure tests of antennas are needed. At present, the fixed unloading truss-frame is used in the deployment test of antenna. [1]When the spacecraft carries out Electro Magnetic Compatibility (EMC) test, it is requested to deploy antenna in EMC test room. However, the space of EMC laboratory is not enough to set up fixed unloading truss-frame. At the same time, metal truss brings great interference to the wireless test signal during EMC test. [2]In the process of using the traditional fixed unloading truss-frame, it is necessary to assemble the truss, release the residual assembly stress, then transfer the spacecraft beneath unloading truss, install hanging device on the guide rail of the unloading truss, and unload the antenna in zero gravity. When switching to the antenna on the other side of the spacecraft for deployment/closure test, it is necessary to change the position of the spacecraft. It means the unloading truss-frame can't be moved while spacecraft should be repeatedly adjusted its attitude. Meanwhile, it takes long time to build up and truss-frame whith more cost and larger occupied space. [3] Such assembly mode leads to complicated operation with long assembly testing time, low efficiency, and small effective safety distance between truss-frame and spacecraft, which brings inconvenience to the operation of personnel and the layout in test room. [4]

Therefore, it is necessary to develop a kind of universal unloading bracket which can be easily moved. It is not only suitable for the deployment/closure of antennas in the EMC test stage, but also can provide stable structural support for the deployment/closure test of various antennas in other test stages, which makes the unloading operation of antennas more convenient. It can move the universal unloading bracket of antennas instead of moving the position of spacecraft. So it cost less time of spacecraft AIT and reduce the operational risk. [5] [6]



2. Structure design of convenient cantilever-unloading bracket for antenna

2.1. Overall Program

To meet the demands of deployment/closure of most spacecraft antennas, a large-span convenient cantilever-unloading bracket for antenna is designed. As shown in figure 1, the universal unloading bracket of the antenna adopts the form of cantilever type. The cantilever part is installed at the top of the main structure, equipping with the hanging mechanism of the air-floated pulley group.

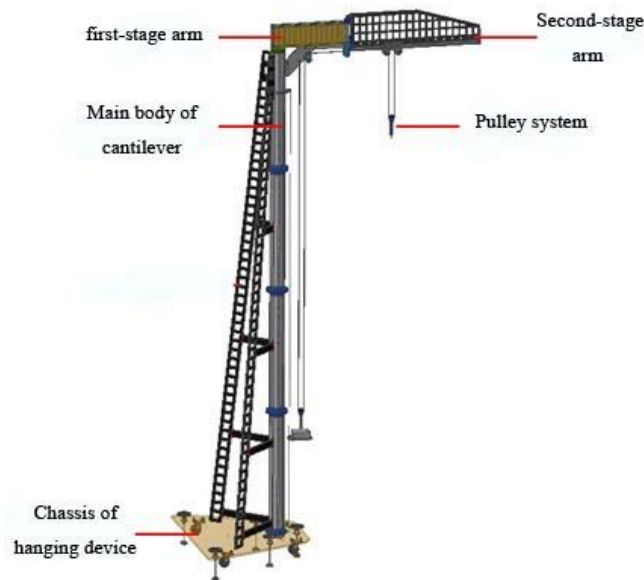


Figure 1. Overall drawing of convenient cantilever-unloading bracket for antenna

The main structure is composed of braces and chassis which can be assembled repeatedly according to the height requirement. The chassis is equipped with counterweight, mobile casters and adjustable supporting casters, which provides the stability of the system and has the functions of parallelism adjustment and overall movement. The cantilever part is mainly composed of a first-stage arm, a second-level deploying arm and a rotating axis; the first-stage arm is firmly connected with the main structure of the antenna universal unloading support; the second-level deploying arm can rotate freely around the first-stage arm; the bottom end of the second-stage deploying arm provides sliding guide. The fixed pulley assembly in the air-floated pulley group is fixed in the area of the second-stage arm, the first-stage arm and the counterweight box. The slider is installed on the guide rail of the second-stage arm and can slide freely along the guide rail. The movable pulley assembly is connected under the slide block through the Kevlar pull rope, and the end of the movable pulley assembly is a cylindrical suspender, which serves as the unloading interface for the antenna (or can be changed to other interface shapes according to its requirements). The size of unloading force is adjusted between pulley groups by Kevlar rope, counterweight box and air floatation mechanism; the counterweight box and Kevlar rope are fixed and guided by the side wall of the main strut to realize the follow-up of the counterweight box along the vertical direction; the whole set of pulley groups is air floatation structure, which can effectively reduce friction and realize zero-gravity unloading of suspended products. In the process of antenna deployment/closure rotation, the position of the hook can be automatically adjusted according to the height of the product. The movable pulley assembly slides along the guide rail and moves up and down through the pulley group. The second-stage deploying arm rotates around the first-stage deploying arm, realizing the coverage of the three-dimensional space.

The antenna universal unloading bracket has the advantages of convenient movement, flexible adjustment, less space resource occupation without limitation of site conditions. It can realize zero gravity unloading of products at any position. After the antenna is deployed and fixed, the antenna universal unloading bracket can be removed without affecting other test performances of spacecraft

and other products. In addition, the system has sufficient stability, simple operation, and effectively avoids the potential safety hazards caused by operating in the tight space around the spacecraft. At the same time, it can meet the requirements of coverage of unloading area in three-dimensional space, and is suitable for most spacecraft antenna deployment/closure test requirements. It can completely replace other existing antenna unloading truss-frames.

2.2. Structural Constitution

The main body of the system is supported and fixed by the chassis of the hanging device which is equipped with supporting feet and universal rollers to adjust the level of the chassis and move the system on the ground, respectively; the supporting chassis is equipped with supporting columns, and the upper end of the column is fixed with a first-stage arm; the end of the first-stage arm is equipped with a second-stage arm through bearings at both upper and lower ends, and the second-stage arm can be rotated around the first-stage arm. The rotation range is larger than 90 degrees; the lower end of the rocker arm is equipped with linear guide rail; part of the pulley group is installed on the slide block of the guide rail to realize zero gravity unloading of the unloaded antenna, which can provide lifting force and a certain distance of lifting height. The hanging point position can be adjusted automatically with the change of the connecting point position.

1) Chassis of hanging device

The chassis of the hanging device provides the installation interface of the main body of the antenna unloading device. It also provides the installation position of power supply, control cabinet, etc. At the same time, the cantilever device is equipped with counterweight to ensure the stability of long-span load and anti-overturning of the unloading device. The lower end of the chassis is equipped with supporting feet and universal rollers, which can adjust the level of the chassis and move the system on the ground respectively. The shape of the chassis mainly refers to the avoidance relationship between the antenna support device and other mechanical equipment.

2) Main body of cantilever device

The main body of the cantilever device is comprised of 4 stainless steel tubes which can be assembled repeatedly. Each section of steel pipe is equipped with hanging points for assembling. Each section is connected by flange, and the chassis is fixed by flange and steel pipe reinforcement. According to the requirements of different working conditions, the total height of the antenna unloading device can be changed by reducing the number of steel tubes.

3) First-stage arm

The first-stage arm is connected with the second-stage arm and the main structure. The connections are removable. During the working period of the whole system, the first-stage arm is a fixed part, the main body is a 20mm thick steel plate whose reinforcement frame is wrapped outside to increase the stiffness of the arm.

4) Second-stage arm

The second-stage arm is connected with the first-stage arm through the hinge structure and provides the running slides of the cantilever system. The structure of second-stage arm is similar to the usually used bracket. In order to further reduce the friction, the guide rail on the second-stage arm adopts the form of air flotation. The second-stage arm and the air flotation guide rail adopt the integrated design. The air flotation slider can move along the air flotation guide rail in a straight line.

5) Pulley system

The pulley system consists of five fixed pulleys and two moving pulleys. The weight on the left side is balanced with the weight of the unloaded object. The weight of the balance is theoretically the same as the mass of the unloaded object (antenna) with the same stroke. During the unloading process, the vertical motion of the antenna will not produce horizontal movement. Besides, the whole pulley system is in complete equilibrium state. When the horizontal external force is applied to the slider, the slider can move freely along the guide rail. The movable pulley provides the connection interface of the unloaded product, and the slider acts as the interface between the cantilever system and the

second-stage arm. There are two steering pulleys at the front end of the first-stage arm to ensure smooth connection of the tether when the second-stage arm rotates to different angles.

3. Performance analysis of convenient cantilever-unloading bracket for antenna

3.1. Friction resistance analysis

Friction is an important parameter for antenna unloading. The friction of the system is mainly produced in three aspects: the friction moment between the first and second-stage arms when the ball bearings rotate; the linear sliding (air floatation) friction between the slideway of the second arm and the cantilever system; the internal friction of the pulley group (air floatation); the rigid resistance caused by the bending of the wire rope.

(1) Friction resistance moment analysis of arm-to-arm rotating joint

A ball bearing is used to connect the first-stage arm and the second-stage arm to generate the friction moment of rotating motion. The friction moment of the bearing can be calculated by the following formula: $M = \mu \times p \times d/2$

Among them, M: friction moment, mNm

μ : The friction coefficient of deep groove ball bearing is 0.0015.

P: Bearing load, N

D: nominal bore of bearing, mm

When the cantilever position of the load is at the end of the linear guide rail of the second-stage arm, the bearing is subjected to the maximum positive pressure. At this time, the suspension point is 2.1 meters away from the rotating shaft, the total load is 900 N, and the span of the two rotary joints of the rocker arm is 300 mm. Therefore, the maximum positive pressure P is $900 \times 2.1 / 0.3 = 6300\text{N}$. Thus, the friction resistance moment M is 0.34Nm. Because the rocker arm is composed of two upper and lower rotary joints, the total rotary friction is obtained. The resistance moment is 0.68Nm.

(2) Friction Analysis of Linear Slide

This frictional force is composed of two parts. The first part is caused by the pressure of the load and the air-bearing pulley assembly on the slideway. The second part is caused by the horizontal error caused by the bending of the arm bar with the cantilever device, which results in the force distribution along the slideway direction of the load.

The friction coefficient of the linear slide is about 0.0003, and the pressure on the slide is $G = 900\text{N}$.

So: $F_1 = 0.0003 \times 900 = 0.27\text{N}$

The components of the load along the slideway are as follows:

$F_2 = (1.65 - 0.45) / 1950 \times 900 = 0.55\text{N}$

So the total $f = 0.55 + 0.27 = 0.82\text{N}$

(3) Internal Friction Analysis of Air Floating Pulley Set

This friction is composed of static pulley and moving pulley. The friction force of the pulley group is proportional to the positive pressure applied on the pulley, and the coefficient of air floatation friction is 0.0003. There are five static pulleys (only four of them actually generate friction) and two dynamic pulleys. The force of each pulley can be easily synthesized.

(4) Rigidity resistance analysis of Kevlar cable

When Kevlar pulls rope around pulley, due to the change of curvature, relative slip occurs between rope strands, resulting in friction and elasticity, which hinder it from adapting to the curvature of pulley rope groove immediately and offset a certain amount outward. Likewise, when the Kevlar pull rope is wrapped around the pulley, it can't immediately restore the straight line state, but generates a deviation value inward, as shown in figure 2. This increases the force arm around the branch and decreases the force arm around the branch. In order to make the pulley rotate, it is necessary to increase the pulling force around the branch which is regarded as rigid resistance.

$G(R+m) = (G+F)(R-n)$

G: Cave pulling force

F: Stiffness Resistance

K: Stiffness Resistance Coefficient

Among them, the stiffness resistance coefficient K is generally determined by experimental method. Under general conditions, the stiffness resistance coefficient K of Kevlar rope is 0.005.

So in this system, the rigidity resistance of Kevlar rope can be calculated.

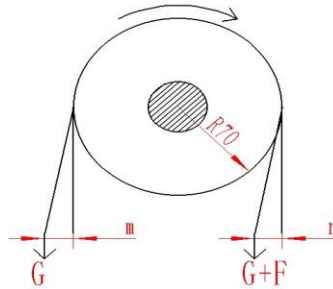


Figure 2. Analysis of Rigidity Resistance of Kevlar Rop

3.2. Anti-overturning design

Because the system itself is a cantilever structure, and the system is under force from upwards when working, it is necessary to carry out anti overturning design for the system, and the position of the system center of mass is shown in figure 3.

According to the system structure, the mechanical model of anti-overturning design is established as follows.

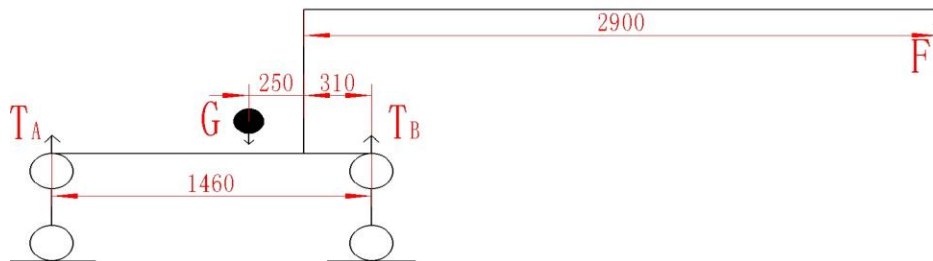


Figure 3. Mechanical sketch of system anti-overturning design

When $T_A = 0$, the system is analysed: $G \times (250 + 310) - F \times (2900 - 310) = 0$, so, $F = 4170$ (N).

When $F > 4170$ N, the suspension load > 417 Kg, the whole system will overturn around point B. The design load of the cantilever system is 90kg. Therefore, the anti-overturning load capacity margin of the system is 363%, and the anti-overturning margin of the system can meet the application requirements.

3.3. Deformation analysis

The total load of the system is 90Kg. we analyze this condition by assuming the hanging point locating at the end of the second-stage arm, the middle part of the arm and the root of the arm. The angle between the second-stage arm and the first-stage arm is 0 and 90 degrees. The results are shown in table 1.

Table 1. Whole Deformation Analysis Unit of Hanging Device: mm

Position where force loading on the second-stage arm	Maximum Deformation under Rated Load		Maximum Deformation Fluctuation under Maximum Load
	The angle between arms is 0 degree.	The angle between arms is 90 degree.	
at the end of arm	1.656	1.616	0.05
at the middle of arm	1.178	1.024	0.154
at the root of arm	0.711	0.456	0.255

From the table above, it can be seen that the maximum deformation is 1.656 mm under the rated load, which meets the requirement of the maximum deformation of the antenna. In addition, according to the trajectory of antenna, the angle of the second-stage arm relative to the first-stage arm is about zero during the unloading of the antenna with 1700mm working distance. Therefore, the deformation during the unloading process meets the requirements of the index.

4. Summary

In this paper, a universal convenient cantilever-unloading bracket for antenna is proposed, which can be easily moved during deployment/closure test during spacecraft AIT. It not only optimizes the traditional operation mode, but also reduces the operation of the spacecraft and the development time of the spacecraft. Besides, the bracket has high unloading accuracy and suits for many working conditions. It can meet the needs of two-dimensional and three-dimensional unloading conditions and reduce the operational risk. The research results of this paper can be widely used in deployment/closure tests of deployable components of various spacecrafts, such as antennas, solar arrays, etc.

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